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TECHNICAL REPORT ECOM-01758-3

GUNN EFFECT DEVICES

THIRD QUARTERLY TECHNICAL REPORT

By

T. O. YEP

OCTOBER 1966

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND • FORT MONMOUTH, N.J.

CONTRACT DA 28-043 AMC-01758(E) - ARPA Order No. 692

HEWLETT-PACKARD COMPANY
HEWLETT-PACKARD LABORATORIES
Palo Alto, California

The work prepared under this contract is a part of PROJECT DEFENDER and was made possible by the support of the Advanced Research Projects Agency under Order No. 692, through the U. S. Army Electronics Command.

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GUNN EFFECT DEVICES

THIRD QUARTERLY TECHNICAL REPORT
15 May 1966 to 15 August 1966

Report No. 3

Contract No. DA 28-043 AMC-01758(E)
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O/S Task No. 7900.21.243.38.00

Prepared by

T. O. Yep

HEWLETT-PACKARD COMPANY
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Palo Alto, California

for

U. S. Army Electronics Command, Fort Monmouth, New Jersey

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ABSTRACT

CW operation of Gunn devices was observed in a Gunn mount and a tunable resonant cavity. The frequency tuning behavior, shift in frequency with changing bias voltage, power output, and average dc sample current of the devices were measured.

Noise measurements on the Gunn oscillators in a resonant cavity showed that FM noise was the predominant type of noise.

PURPOSE

A development program is to be conducted aimed at the utilization of the Gunn effect for various types of microwave generating devices in the 1 to 50 GHz frequency range. Spectral line width should be less than 10 kHz and operation should be in a single mode. Output power should be at least 25 mW in CW operation and 3W peak in pulsed operation with a conversion efficiency of at least 3%. CW operation should be obtained in ambient temperatures from -25°C to +60°C with a single device.

Application of these devices for amplification and modulation is to be investigated.

FOREWORD

The work reported on in this report has been authorized by the Contracting Officer, Mr. Edgar D. Fitzgerald, Electronic Components Laboratory, U. S. Army Electronics Command, Ft. Monmouth, New Jersey, under Contract No. DA 28-043 AMC-01758(E) and titled "Gunn Effect Devices". The Project Engineer at the U. S. Army Electronics Command is Mr. Murice Druesne.

The work has been performed at Hewlett-Packard Laboratories under the supervision of Dr. M. M. Atalla. The report has been prepared by T. O. Yep. Major contributions during this report period have been made by G. W. Mathers. B. Farrell, H. Luechinger and L. Freemen have also contributed significantly. Discussions with C. F. Quate were beneficial.

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GUNN EFFECT DEVICES

THIRD QUARTERLY TECHNICAL REPORT

I. INTRODUCTION

A considerable portion of the effort this last quarter has been spent on the evaluation of the rf performance of two groups of Gunn oscillator samples.

Both groups of samples are 375 x 375 μm square chips fabricated from 1 Ω-cm boat-grown GaAs. One face of the chip has an ohmic contact over the whole surface, whereas the other face has a small circular dot in the center as the ohmic contact. As a result of this asymmetric contact configuration, the active volume of the device is approximately a small cylinder under the circular dot.

The group of samples designated ES2 have a 50 μm diameter small contact and a thickness of 15 to 20 μm, while the ES8 series of samples have a 95 μm diameter small contact and a thickness of 20 to 25 μm. The samples listed have all been operated CW in a resonant tunable cavity and in a non-resonant or Gunn mount with a one ohm load resistor. Of the samples from each group that have been tested and operated CW (20 to 30 of each), 80% have exhibited essentially the same rf behavior. The results for two typical samples are summarized in the following discussion.

II. CHARACTERISTICS OF OSCILLATION

A summary of the threshold voltage, V_{th}, threshold current, I_{th}, and other pertinent results obtained for a typical sample from each of the two groups of Gunn devices is provided in Table 1.

Figures 1 and 2 illustrate the tuning characteristics for samples ES2 and ES8, respectively, in a resonant cavity under fairly light loading. In both samples the notable features of the tuning are:

(1) Jumping between various cavity modes occurs.

(2) No different or peculiar behavior is observed when tuning through the Gunn frequency.

(3) As the loading on the sample is increased, the tuning range decreases from both ends.

(4) The upper frequency limit, the lower frequency limit, and the Gunn frequency decrease as the applied dc voltage is increased. Both the upper and lower frequency limit decrease by about the same amount with increasing applied dc voltage.

The upper frequency limit is explainable in terms of the effective conductance of the device; the upper frequency limit occurs when the effective conductance changes fairly rapidly from negative to positive at some frequency somewhat above the Gunn frequency, f_G. The lower frequency limit is determined by a combination of the particular higher frequency cavity resonances, the operating frequency, and the Gunn frequency. As yet no simple or easily understood complete explanation for this mode and frequency switching has been obtained.

TABLE 1

	ES2A-7A	ES8A-1GG
Contact dot diameter	50 μm	95 μm
Thickness of sample	≃ 18 μm	≃ 23 μm
Low-Field dc Resistance	65 Ω	34 Ω
Gunn Mount:		
V_{th}/I_{th}	7.26 V/95 mA	8.5 V/210 mA
Gunn frequency, f_G	9.0 GHz at 7.26 V 8.52 GHz at 10 V	6.17 GHz at 8.5 V 5.87 GHz at 9.5 V 5.22 GHz at 11.5 V
Resonant Cavity:		
V_{th}/I_{th}	6.05 V/95 mA	8.15 V/210 mA
Input Power at Threshold	0.58 W	1.71 W
Input Power above Threshold	0.81 W at 9.5 V	1.95 W at 10.5 V
Maximum tuning range	4.25 to 9.3 GHz	2.27-6.55 GHz
Bias Voltage for Sample Current Min.	8.5 to 90 V	11 V
Maximum power output	2 - 4 mW	9 - 11 mW
Maximum Positive $\Delta f/\Delta V$*	+8.0 MHz/V at 8.0 GHz	+23MHz/V at 6.0 GHz
Maximum Negative $\Delta f/\Delta V$*	-8.0 MHz/V at 4.75 GHz	-.50 MHz/V at 2.5 GHz
Frequency for zero $\Delta f/\Delta V$*	6.25 GHz	3.5 GHz
Measured Device Capacitance	0.467 pf at 5.039 GHZ 0.510 pf at 8.735 GHz	0.67 pf at 4.83 GHz
Calculated Device Capacitance	0.0078 pf	0.0273 pf

*

$\Delta f/\Delta V \equiv$ Frequency shift/change in bias voltage.

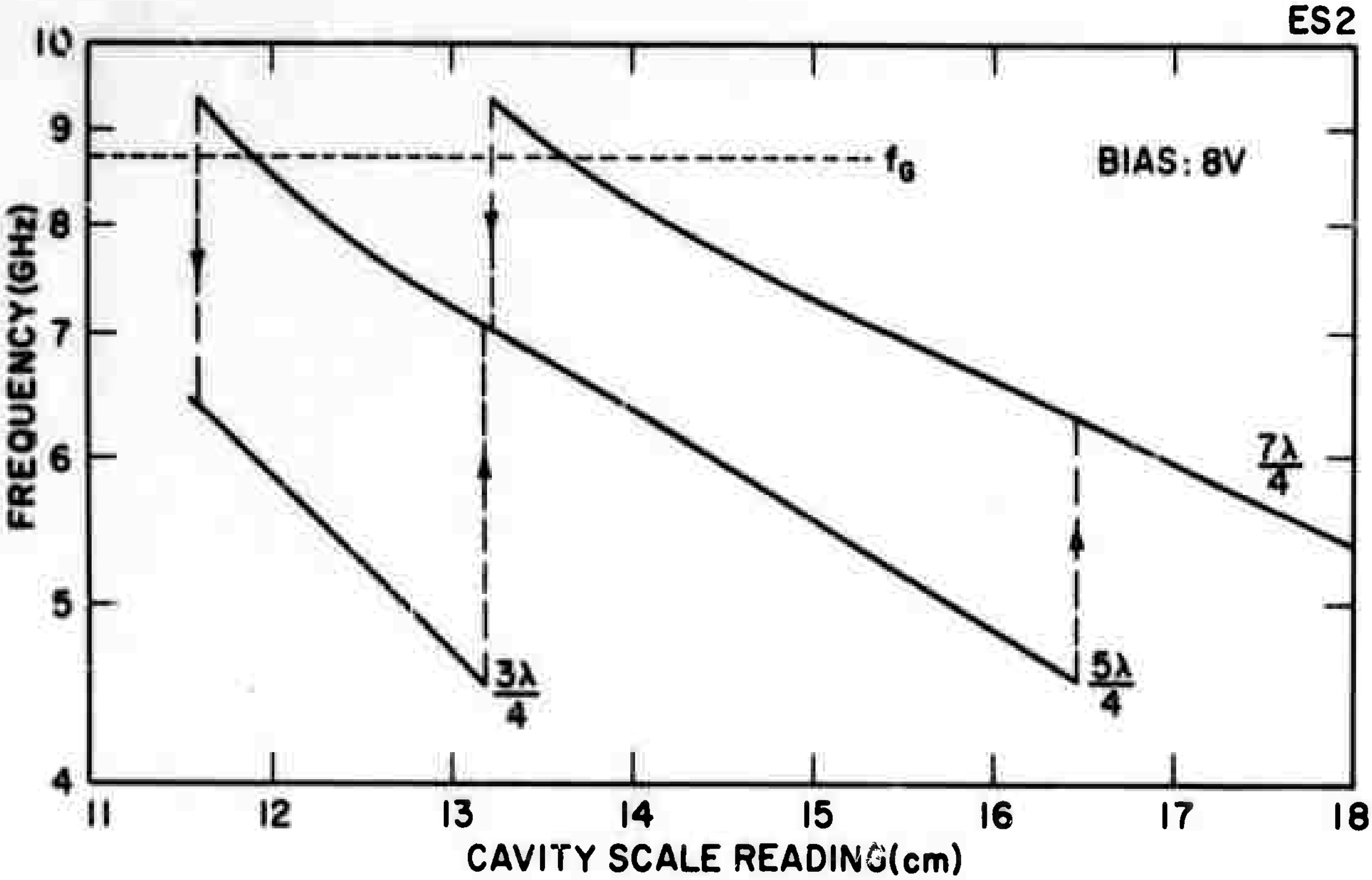

FIGURE 1: Tuning of sample ES2 in a resonant cavity at a bias voltage of 8 V.

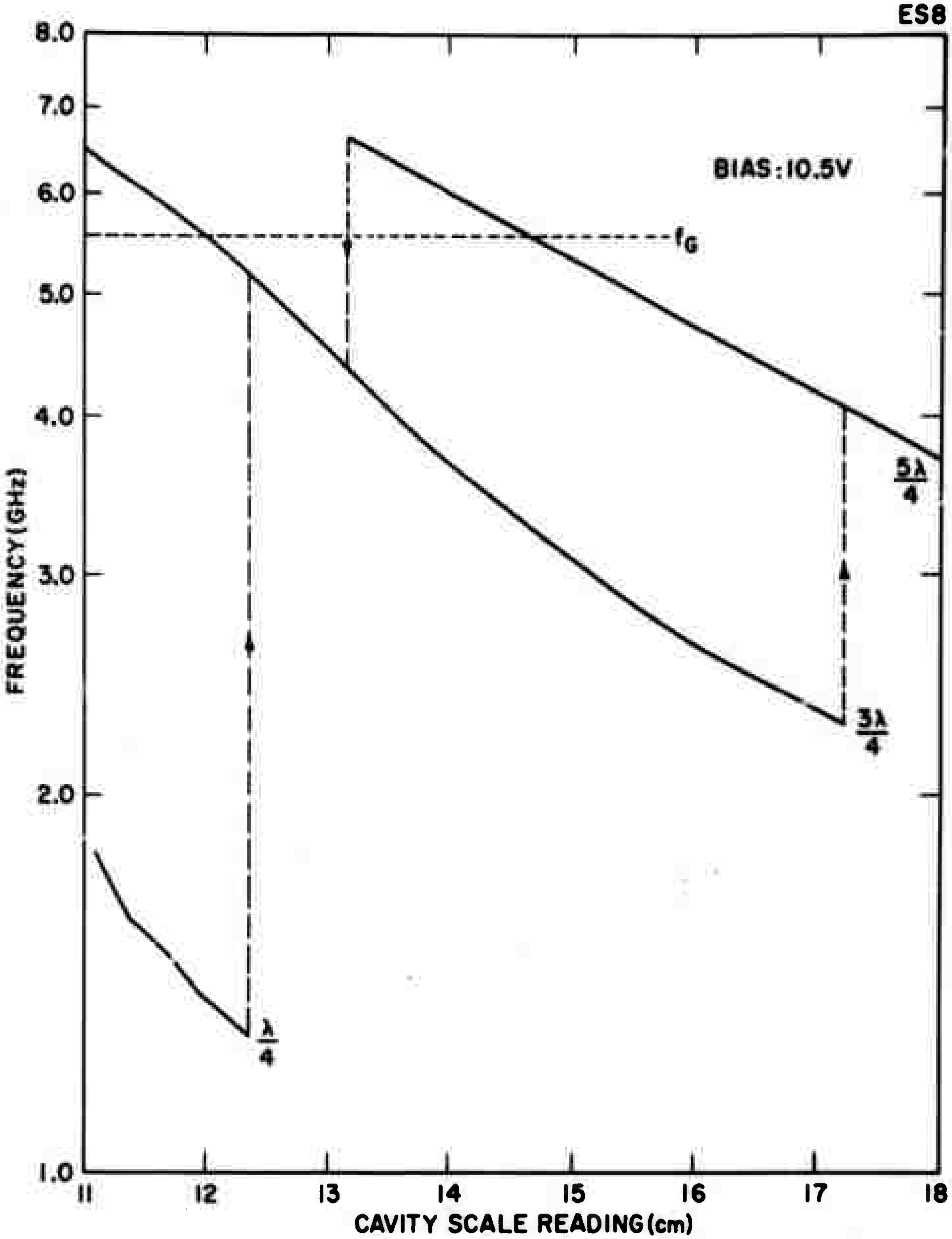

FIGURE 2: Tuning of sample ES8 in a resonant cavity at a bias voltage 10.5 V.

For different cavity tunings of sample ES2 while operating in the $5\lambda/4$ mode, the frequency shift from the cavity frequency at a bias of 7V as the applied dc voltage is increased above 7V is presented in Figure 3. Similarly, Figure 4 contains the frequency shift of sample ES8 with respect to the frequency at a bias voltage of 10.5 V as the dc bias voltage is changed. The ES8 sample was operating in the $3\lambda/4$ cavity mode. For both samples, the operating frequency at which the frequency shift-to-bias voltage change ratio, $\Delta f/\Delta V$, is approximately zero is $0.64 \times f_G$. For frequencies above $0.64 \times f_G$, $\Delta f/\Delta V$ is positive, while for frequencies below, $\Delta f/\Delta V$ is negative. The absolute value of $\Delta f/\Delta V$ depends on the operating cavity mode. $|\Delta f/\Delta V|$ is less for the higher order modes and is approximately proportional to $1/n$, as is predicted by the theory. Other factors influencing $\Delta f/\Delta V$ are the loading on the sample and the thermal frequency drift.

The power output and dc sample current as a function of frequency for sample ES2 under constant bias and medium loading conditions are shown in Figure 5. Likewise, Figure 6 depicts the frequency dependence of the power output and dc sample current for sample ES8 under constant bias and medium loading conditions. The salient features of the curves are the rise in average sample current near the low frequency end, the large steady drop in power output as the upper frequency limit is approached, and the somewhat constant power output as the low frequency limit is neared.

Figures 7a and 7b show the power output and average dc current of sample ES2 as a function of applied dc voltage for various frequencies.

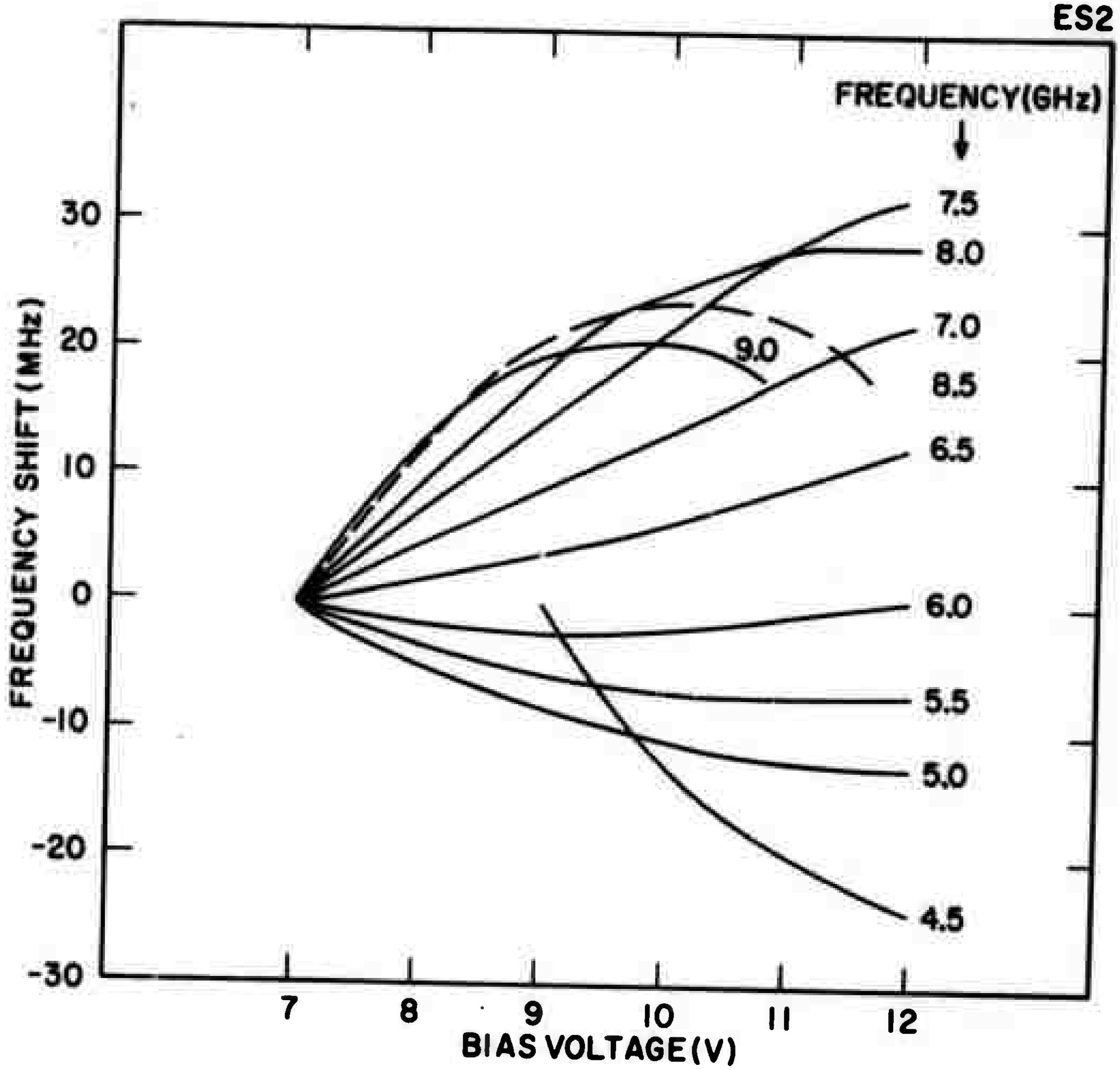

FIGURE 3: Bias voltage dependence of the shift in frequency from the cavity frequency at a bias of 7 V for sample ES2.

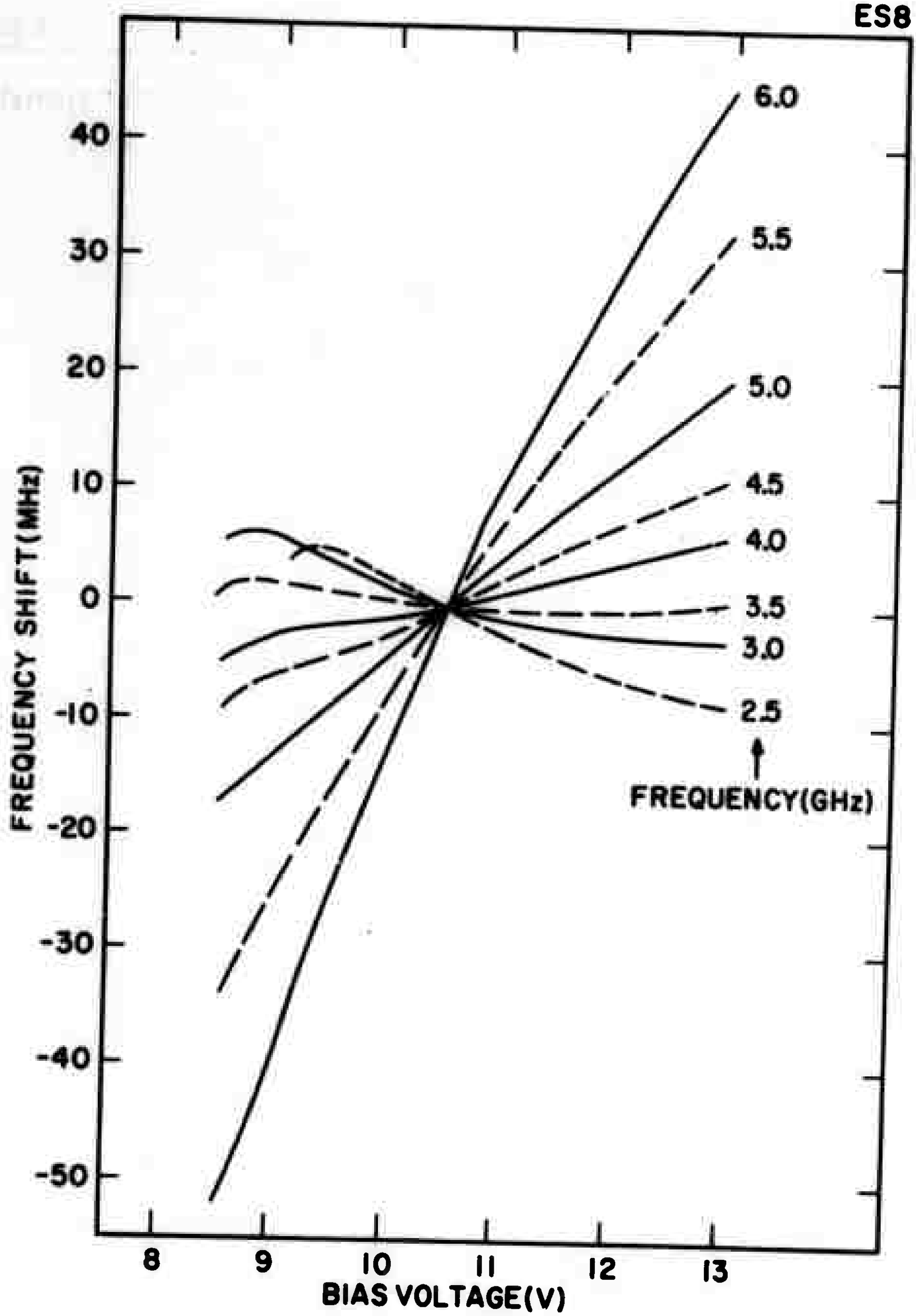

FIGURE 4: Bias voltage dependence of the shift in frequency from the cavity frequency at a bias of 10.5 V for sample ES8.

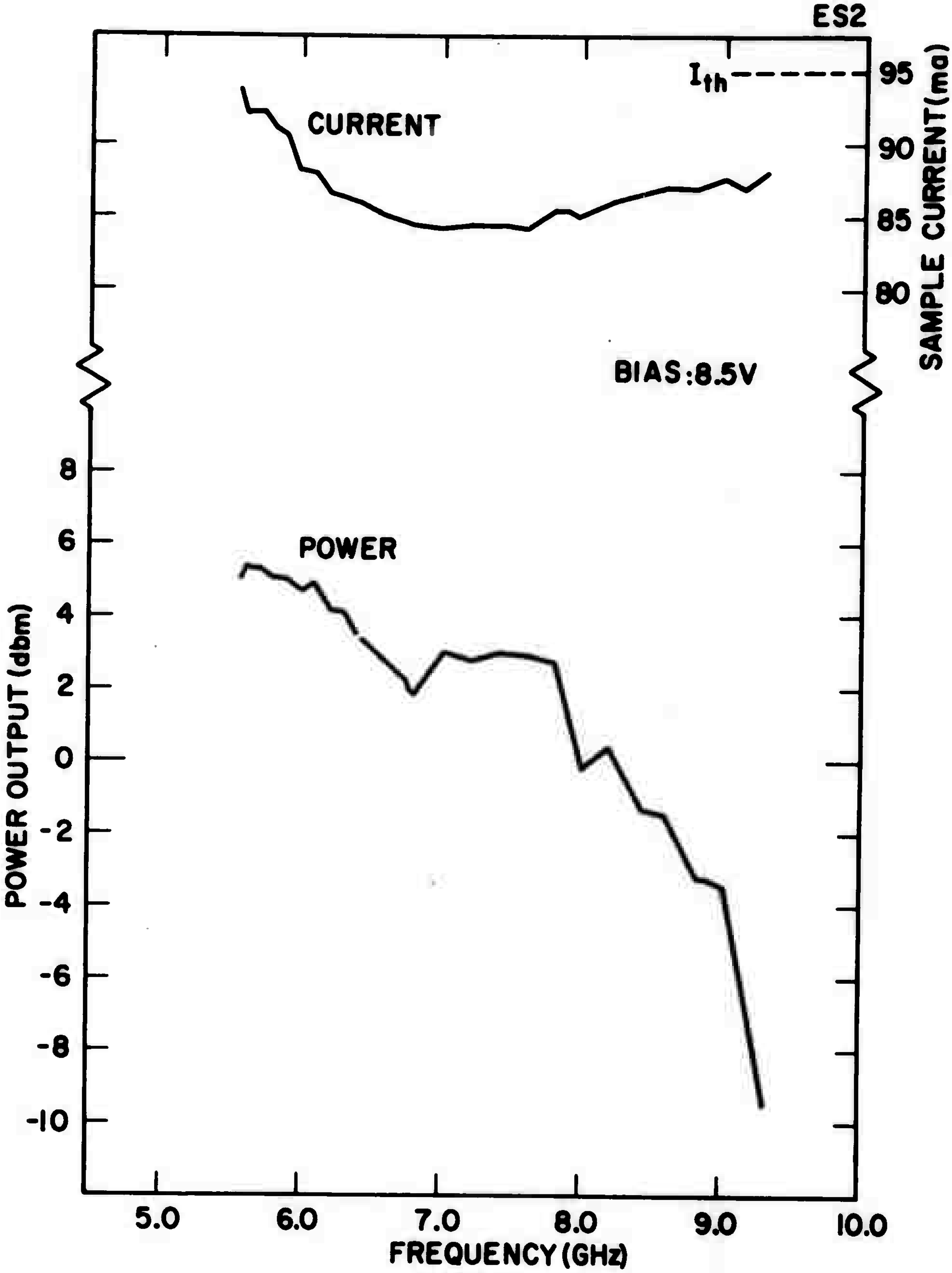

FIGURE 5: Power output and dc sample current of sample ES2 as a function of frequency at a bias voltage of 8.5 V.

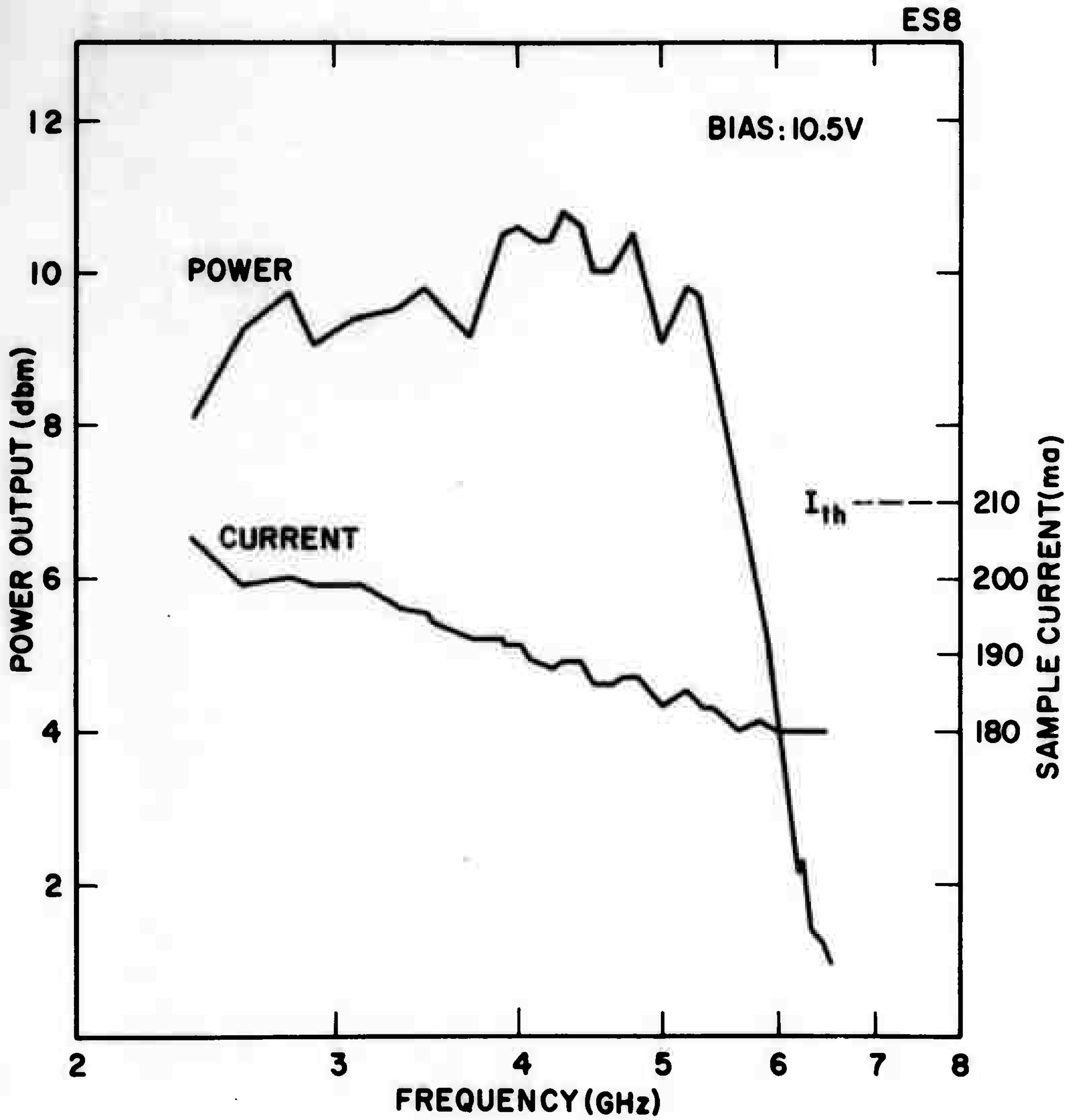

FIGURE 6: Power output and dc sample current of sample ES8 as a function of frequency at a bias of 10.5 V.

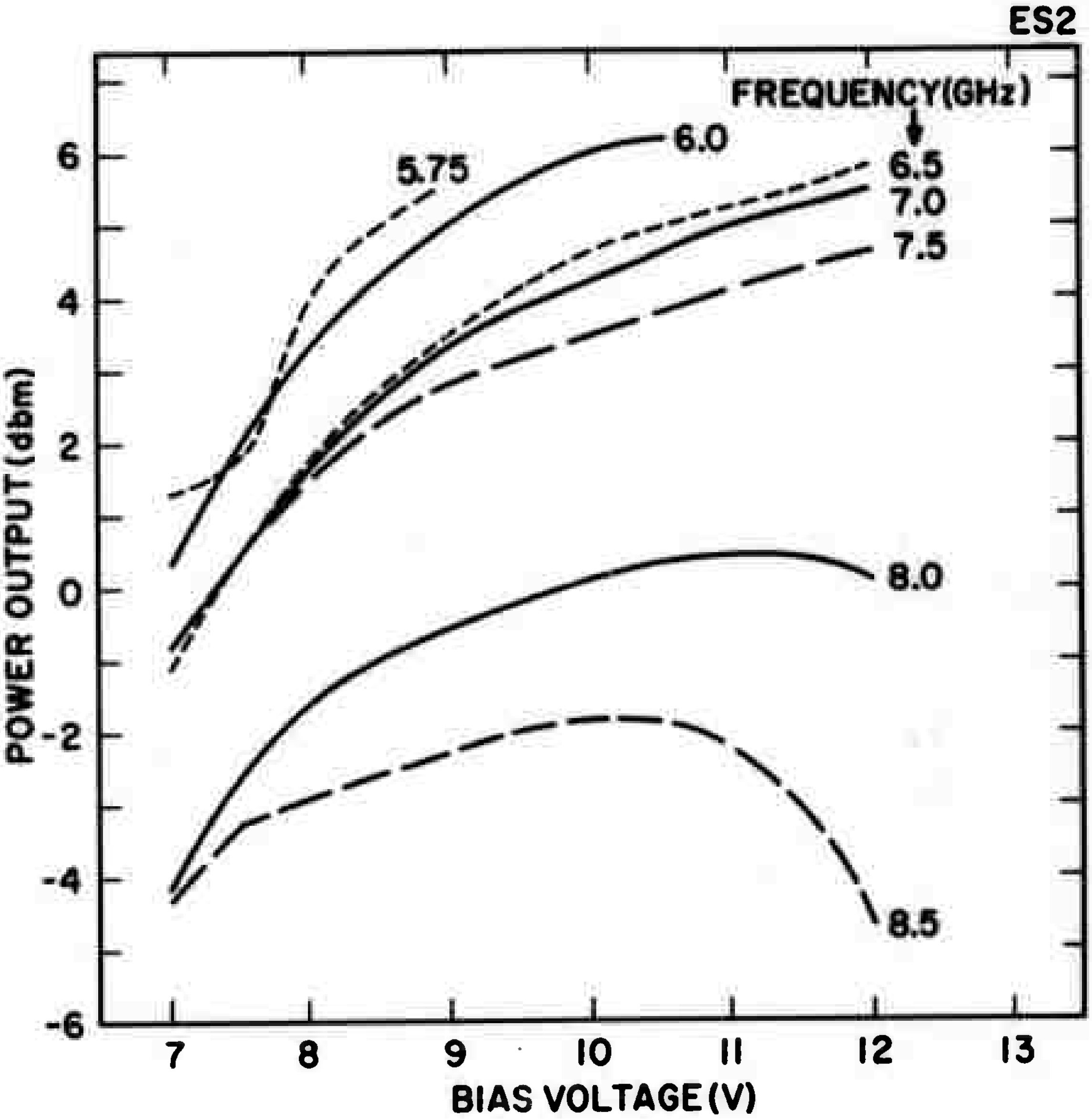

FIGURE 7a: Power output dependence of sample ES2 on the dc bias voltage for various frequencies.

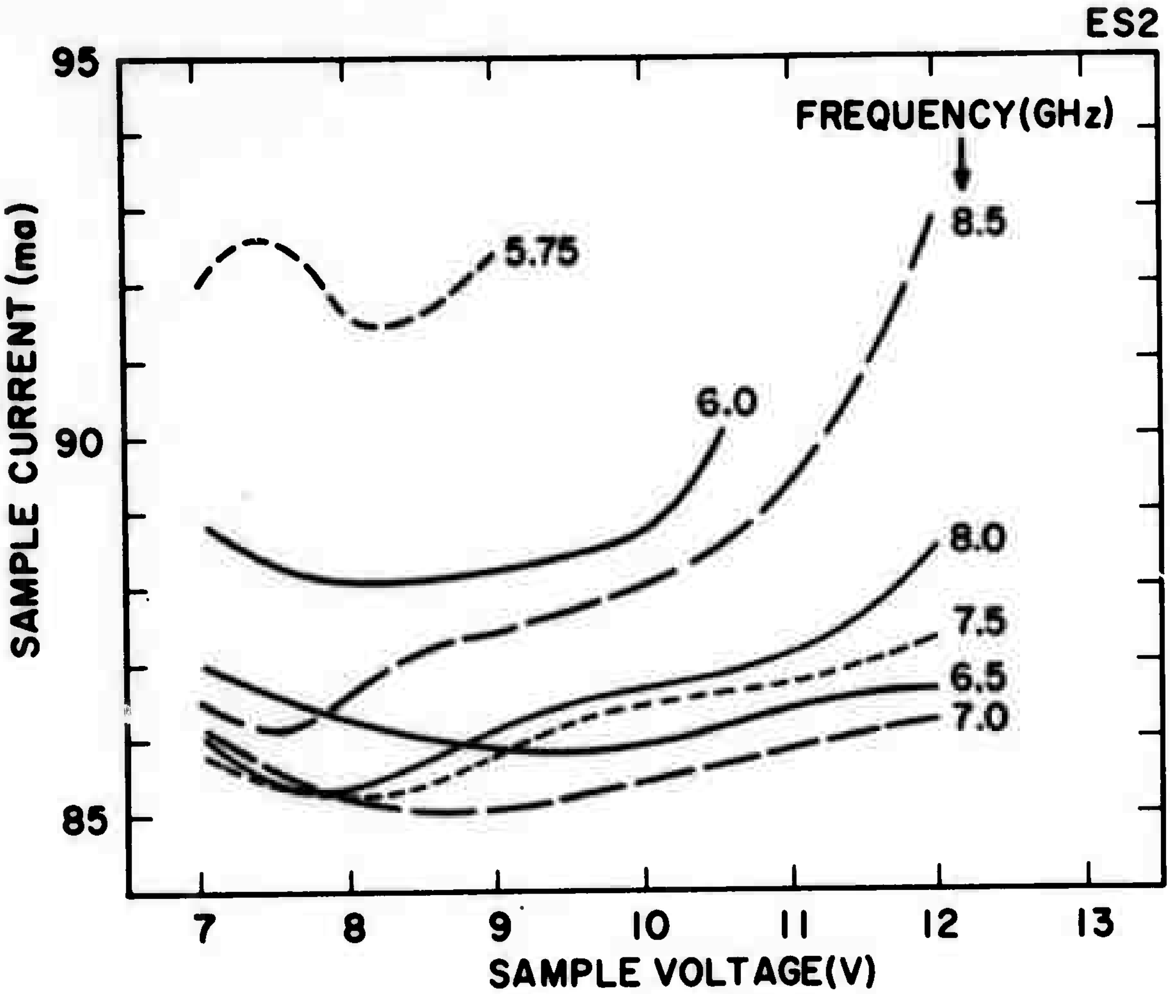

FIGURE 7b: Dependence of dc sample current for sample ES2 on the dc bias voltage for various frequencies.

Figures 8a and 8b are similar curves for sample ES8. From Figures 7b and 8b a minimum in each of the current curves is evident two or three volts above the threshold voltage. Part of the rise in current at higher voltages may be due to thermal heating of the device. For the different cavity modes, the power output and dc current are essentially unchanged for the same operating frequency and dc bias voltage.

An analysis of the experimental data of this report and of the results of the previous pulsed experiments on samples whose lengths are longer than the ES2's or ES8's indicates that the operation of all of these Gunn devices can be qualitatively explained on the basis of a tunable domain mode. The tunable domain mode may be characterized by the formation of dipole domains near the cathode contact of the sample. These domains propagate along the length of the sample toward the anode contact when the sample is in a tunable resonant cavity in the same way as when the device is operating in a non-resonant low impedance circuit. In the latter case, a single frequency output is produced that is equal to the propagation velocity of the domain divided by the sample length (v_D/ℓ). In the resonant circuit case, the domain velocity and the partial or complete transit of the domain from the cathode to the anode is determined by the combined dc and ac voltages across the sample. The resulting terminal current as a function of time for the sample in a non-resonant low impedance circuit and in a resonant circuit are illustrated in Figures 9a and 9b, respectively.

The operation of the samples in the tunable domain mode from a qualitative point of view is compatible with the approximate equivalent circuit

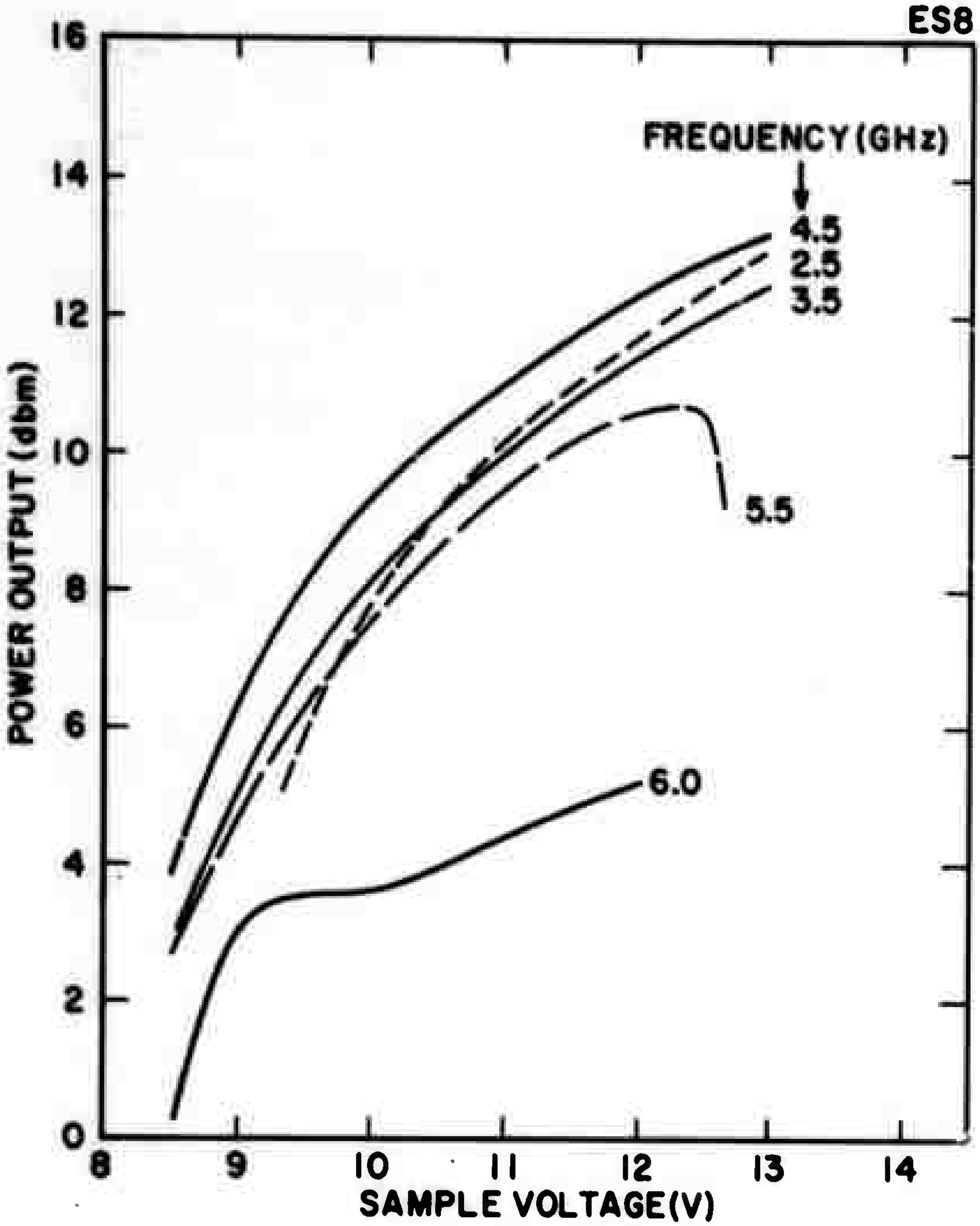

FIGURE 8a: Power output dependence of sample ES8 on the dc bias voltage for various frequencies

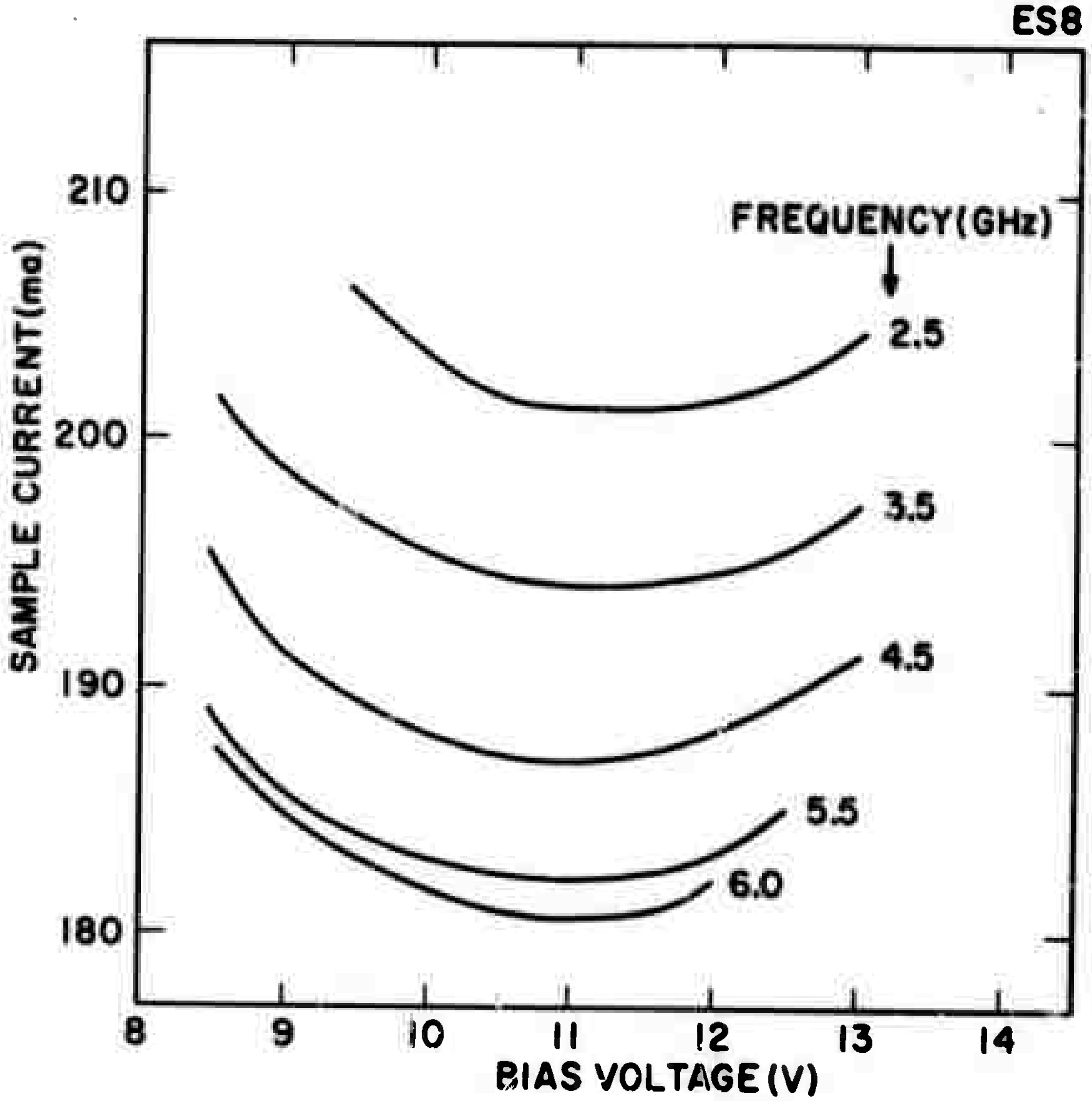

FIGURE 8b: Dependence of dc sample current for sample ES8 on the dc bias voltage for various frequencies.

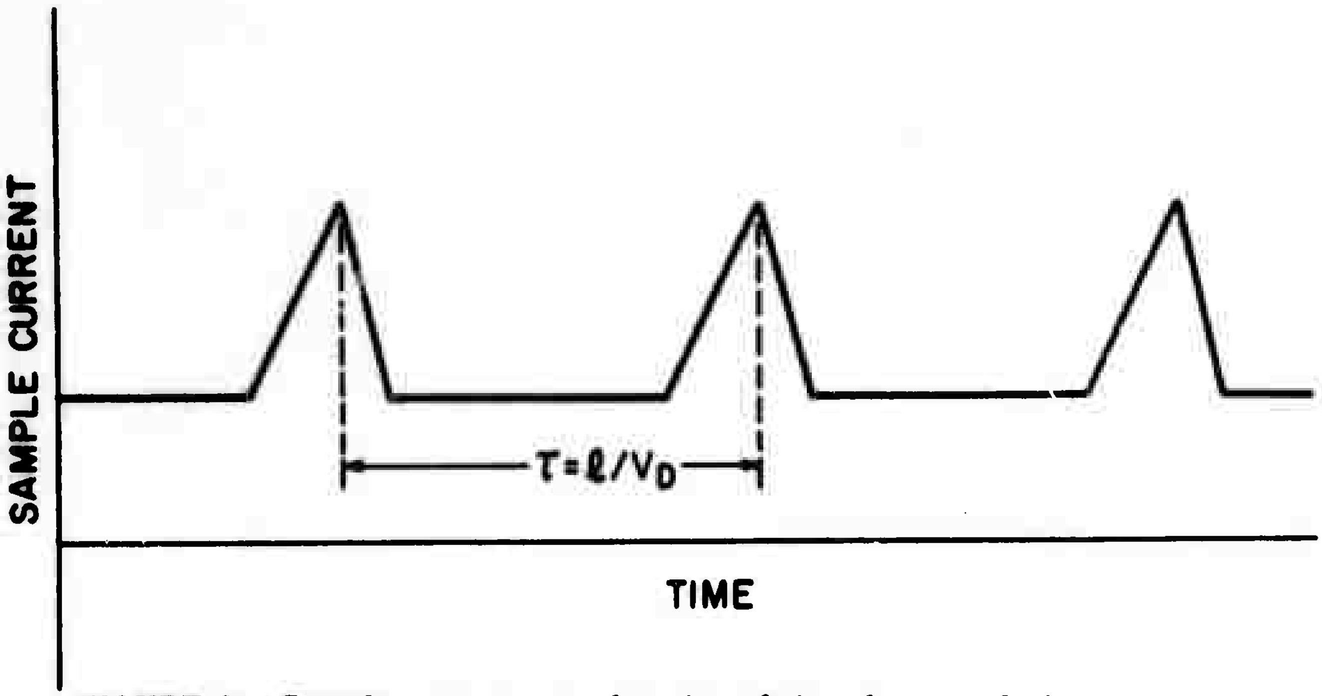

FIGURE 9a: Sample current as a function of time for sample in non-resonant circuit

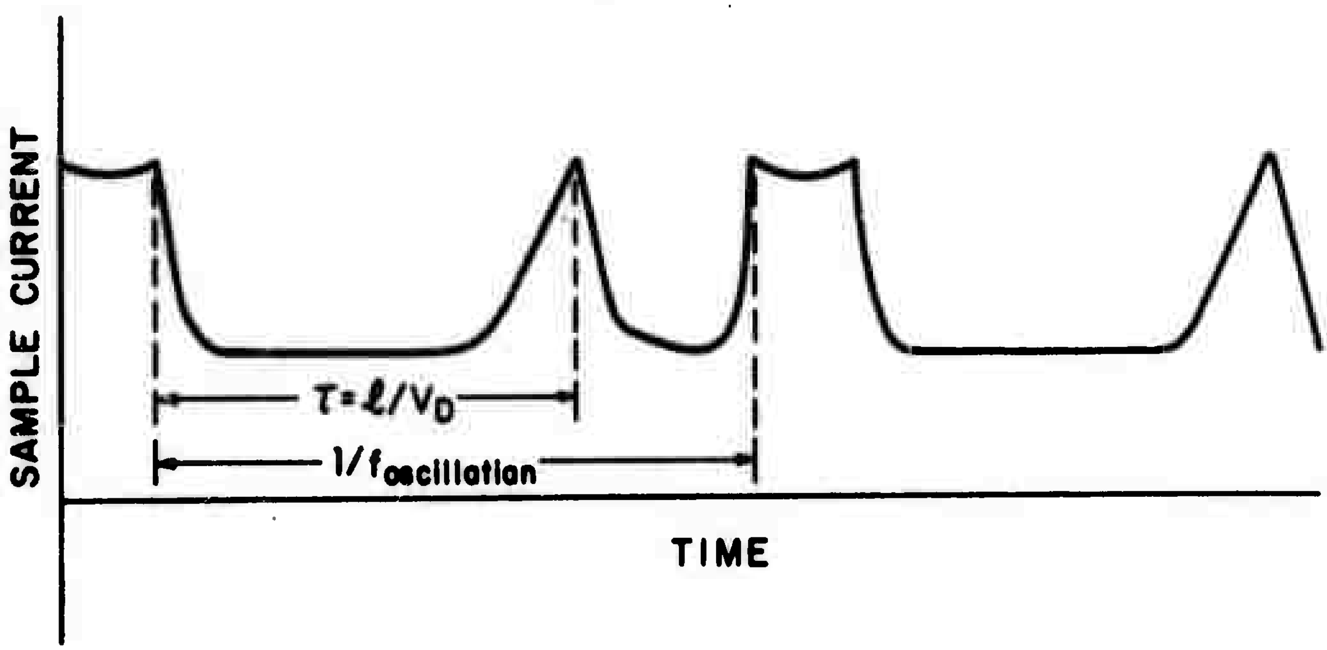

FIGURE 9b: Sample current as a function of time for sample in resonant circuit

shown in Figure 10. The appropriate circuit elements of the equivalent circuit are determined by the sample geometry and doping of the bulk material. C_s is the low field capacity of the sample, R_s the low field resistance of the sample, C_D the domain capacity ($\approx C_s \times 1/W_D$), V_D and I_D the domain voltage and current, and W_D the width of the domain for the steady state V_D. L is an inductance whose value is adjusted so that the short circuit resonant frequency of the circuit is equal to f_G. R_N is the negative resistance of the domain as given by dV_D/dI_D, the reciprocal of the slope of the I_D vs V_D curve given in Figure 11. A more complete analysis of this circuit is now being formulated using a computer program and additional experimentation.

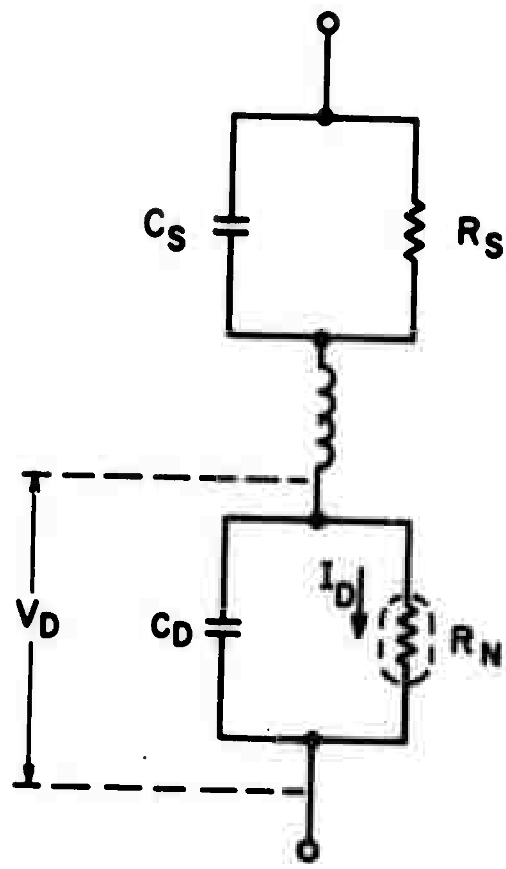

FIGURE 10: Equivalent Circuit of Gunn Device

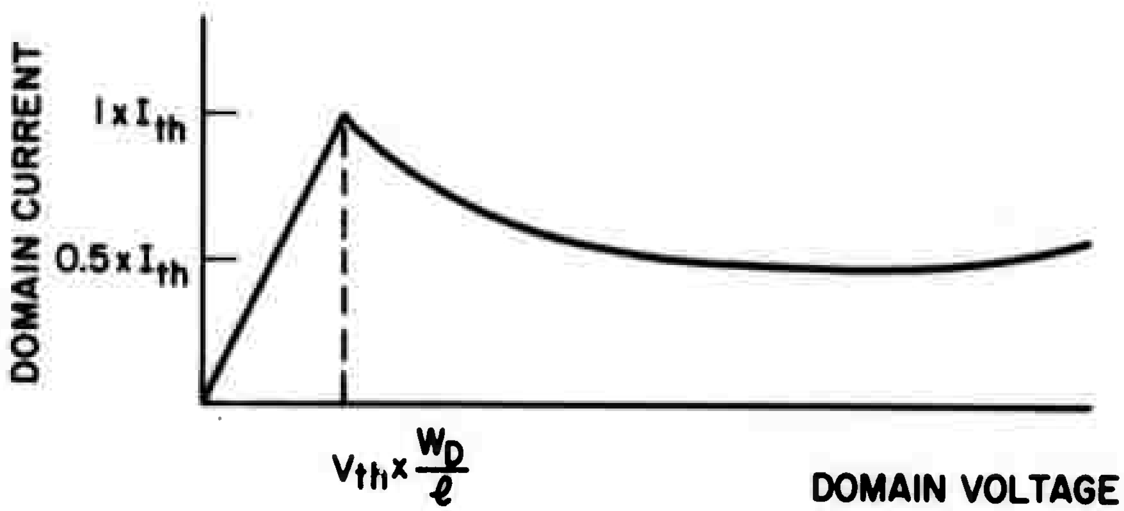

FIGURE 11: Domain voltage versus domain current

III. NOISE

AM and FM noise measurements were made on the ES8 and ES2 samples operating in a resonant cavity. The noise behavior of the ES8's and ES2's was similar in magnitude after the differences in the Gunn frequencies and in the threshold voltages were taken into account.

The FM noise was measured by observing the rms FM deviation at 1 kHz from the frequency of oscillation using a receiver bandwidth of 200 cps. Figure 12 presents the FM noise for ES2 and ES8 samples as a function of the frequency of oscillation. Figure 13 illustrates the bias voltage dependence of the FM noise for both samples.

The AM noise sidebands were found to be on the order of 70 db below the FM sidebands.

Several Gunn devices from the same material and with essentially the same electrical contacts as the ES8 and ES2 samples were cleaved or angle lapped through the contact region. Staining of the cleaved or angle-lapped region revealed a ragged junction at the interface of the alloyed contact and the GaAs. Domains formed at different points on the ragged contact would have different distances to travel across the sample and, thus, different transit times. This ragged contact junction may be a possible mechanism of the FM noise. However, other noise mechanisms certainly are a possibility. Future investigations will be aimed at determining what the sources of noise are.

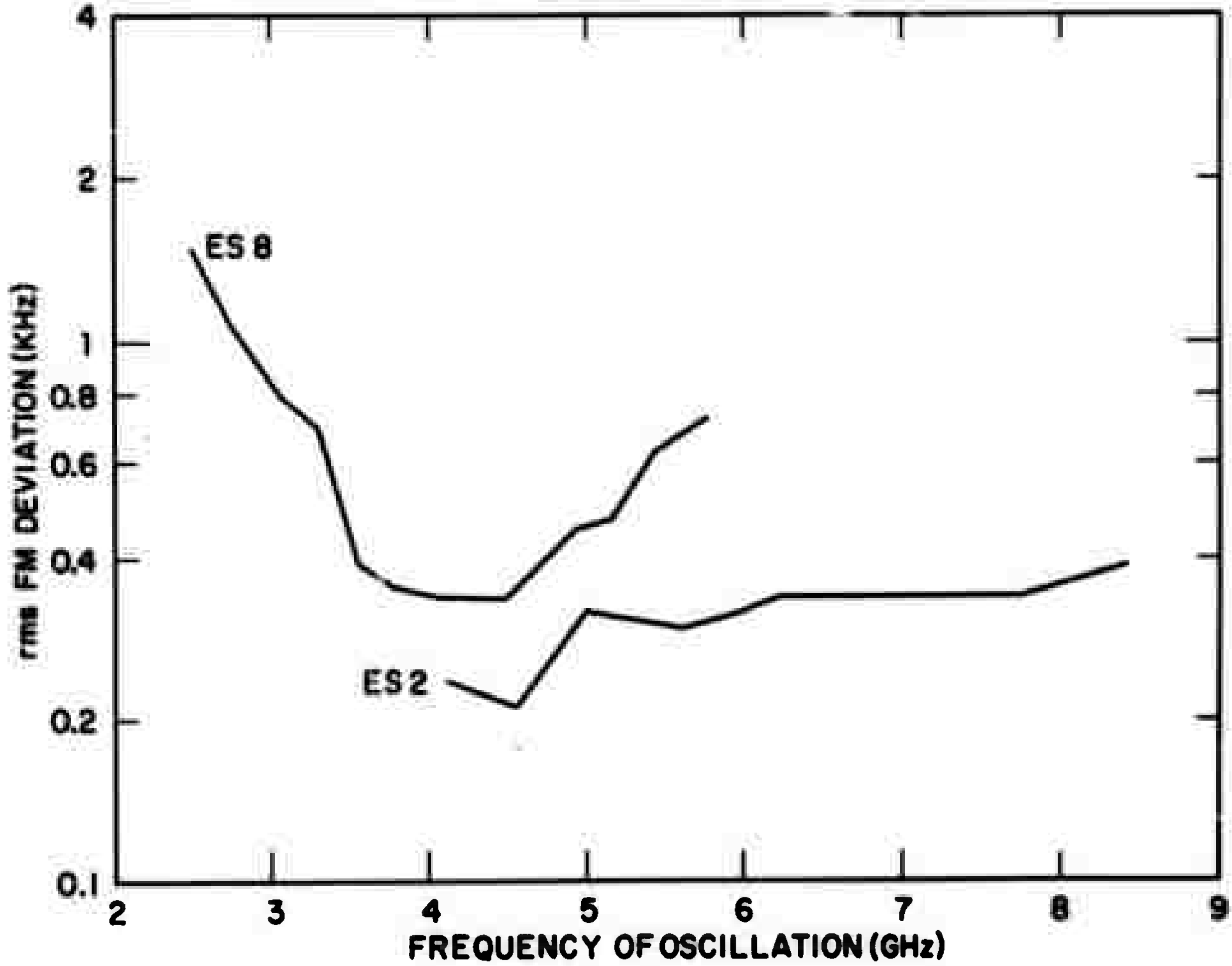

FIGURE 12: FM deviation (rms) at 1 kHz from frequency of oscillation as a function of the frequency of oscillation.

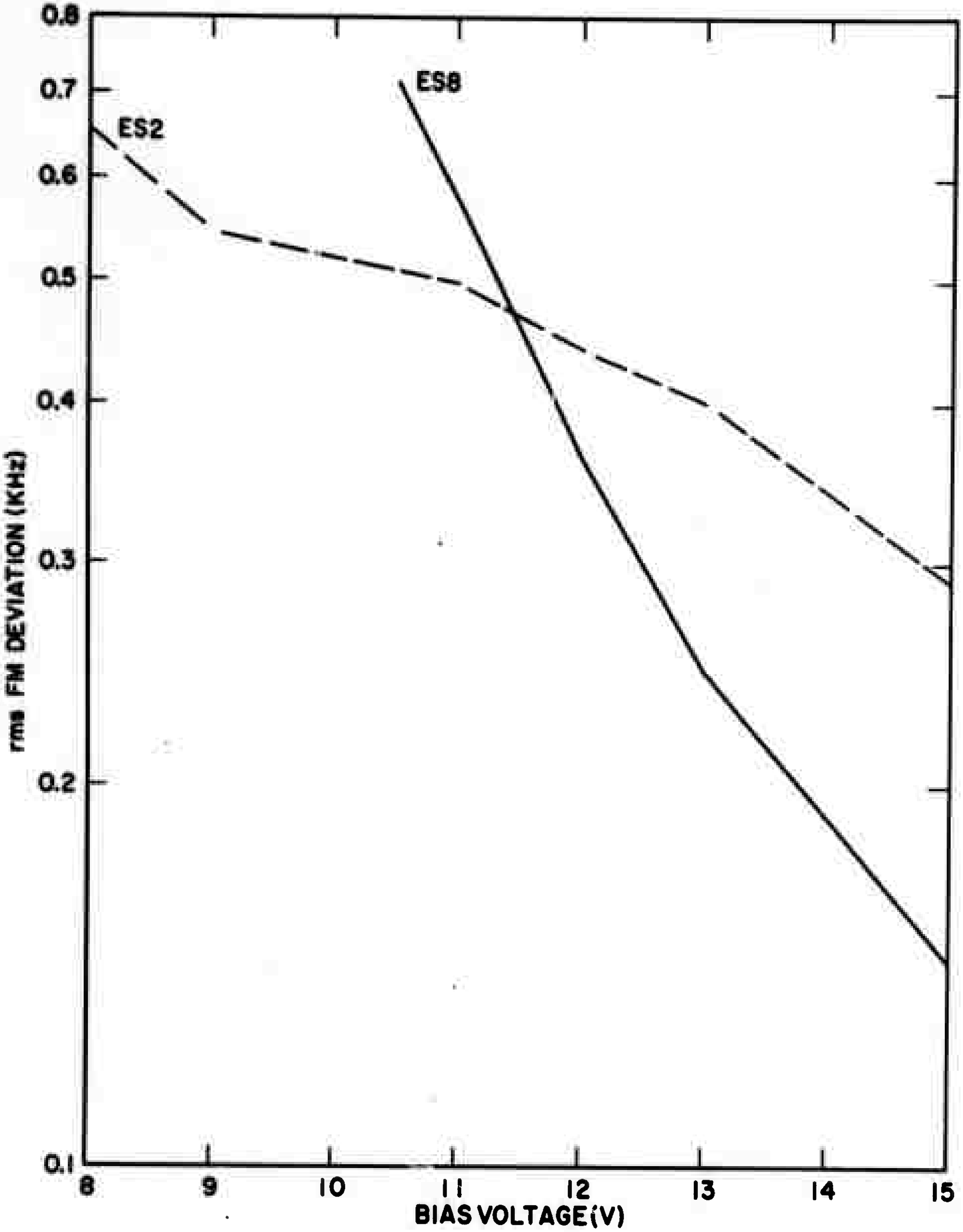

FIGURE 13: FM deviation (rms) at 1 kHz from frequency at oscillation as a function of dc bias voltage.

IV. CONCLUSIONS

Two groups of samples both with an asymmetric contact configuration, but differing in thickness and in the diameter of the small contact, operated CW in both a Gunn mount and a tunable resonant cavity. The oscillatory behavior as typified by the two samples, viz., the frequency tuning range, frequency shift-to-bias voltage change ratio, power output, and average dc sample current, showed a remarkable similarity between the two sets of devices when the Gunn frequency, threshold voltage, and threshold current are taken into consideration.

A tunable domain mode and an equivalent circuit for the Gunn device can qualitatively explain the oscillatory performance of the Gunn oscillator.

The noise from the Gunn oscillator was found to be predominantly FM noise. The definite mechanism of the noise is not as yet known.

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13. ABSTRACT

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